



U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Extinguishing Agents for Protection of Occupied Spaces in Military Ground Vehicles

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Background



- This brief is an update of a presentation made at the 2010 NFPA Suppression/Detection Symposium (available at: www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA517470) and, in an updated form, published in NFPA's Fire Technology Journal (May 2012).
- The US Army is in the process of modernizing legacy vehicle platforms, including Automatic Fire Extinguishing Systems (AFES).
- Legacy vehicles use Halon 1301 or HFC-227BC to protect the crew. 1301 has high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). HFC-227 has high GWP.
- The Army is considering replacing legacy agents with more environmentally friendly suppression agents.
- TARDEC was tasked to test alternate agents, including FK-5-1-12.
 - FK-5-1-12 suppression agent has zero ODP and low GWP. The manufacturer has claimed that it is essentially a drop-in replacement for 1301 or HFC-227ea.

Current Applications



Agents used in US Ground Vehicle Automatic Fire Extinguishing Systems (AFES)

Platform	Crew AFES Agent	Engine AFES Agent
Abrams Main Battle Tank (M1)	Halon 1301	Dry Chemical (NaHCO ₃)
Bradley Fighting Vehicle (BFV)	Halon 1301	HFC-227ea & HFC-125
Field Artillery Ammunition Support Vehicle (FAASV)	*Halon 1301	HFC-227ea
STRYKER Brigade Combat Team (BCT)	HFC-227BC	HFC-125
Up-Armored HMMWV (UAH)	HFC-227BC	None
Mine Resistant Ambush Protected (MRAP)	HFC-227BC	Various including dry chemical, HFC-125 and HFC-227ea
USMC Light Armored Vehicle (LAV)	HFC-227BC	HFC-125
MRAP All-Terrain Vehicle (M-ATV)	HFC-227BC	Solid propellant
**Joint Light Tactical Vehicle (JLTV)	HFC-227BC	TBD

*Upgrade to HFC-227BC in process
NOTE: this list is not comprehensive.

**In development

Agent Comparisons



	Property	Halon 1301	HFC-227ea ^a	FK-5-1-12 ^b	Water+ ^c	Dry Chemical ^d
Environmental	Ozone Depletion Potential ^e	16	0	0	0	0
	Global Warming Potential ^f	6900	3500	1	0	0
	Atmospheric Lifetime (yr)	65	33	0.014	0	0
Safety	Design Concentration (%v/v)	5	8.7	6.7 ^g	~300 g/m ³	~300 g/m ³
	NOAEL ^h (%)	5	9.0	10	NA	TBD ^j
	LOAEL ⁱ (%)	7.5	>10.5	10	NA	TBD ^j
Physical	Boiling Point (°C)	-58	-16	49	115	N/A
	Vapor Pressure @ 21°C (bar)	13.7	4.1	0.41	0.03	N/A
	Liquid Density (g/cm ³)	1.56	1.39	1.60	1.27	2.16
	Molecular Weight (g/mol)	149	170	316	31	84
	Heat of Vaporization (J/g)	117	132	88	>2250	N/A

a) HFC-227ea is a form of heptafluoropropane and is sold as a fire extinguishing agent. b) FK-5-1-12 is a perfluorinated six-carbon ketone manufactured and sold as a fire extinguishing agent. c) Water with 50% Potassium Acetate. d) Values given are for sodium bicarbonate-based dry chemical. Potassium bicarbonate crystal density is 2.17 g/cm³. e) CFC11 baseline, ref. 8. f) CO₂ baseline, ref. 9. g) Concentration advised by the agent manufacturer for this application. h) No Observed Adverse Effects Level. i) Lowest Observed Adverse Effects Level. j) Acceptable concentration levels for this application to be determined by the USA.

Exploratory Tests



Purpose

TARDEC's Exploratory tests are intended to compare various suppression agents, including new, more environmentally friendly ones, with those currently deployed.

Approach

- Three extinguisher suppliers supported the tests (12/08-9/09) – they were asked to provide suppression systems that would yield marginal suppression 'passes' and 'failures' based on current vehicle performance criteria.
- The tests were conducted in a 260 ft³ (7.36 m³) box with relatively little clutter, no stowage, and no active air flow.



Tests (continued)



Seven test series conducted between Dec08 and Sep09

- 157 live-fire tests
- 9 suppression agents
 - Halon 1301 - 'halon' (*used in legacy vehicles*)
 - Halon 1301 with Dry Chemicals (DC) – 'halon+' & 'halonK'
 - HFC-227ea with DC – 'HFC227BC' (*used in vehicles since 2001*)
 - FK-5-1-12
 - FK-5-1-12 with DC – 'FK-5-1-12+'
 - Water with Potassium Acetate – 'water+'
 - Two Dry Chemicals – Sodium (+) and Potassium (K) Bicarbonates
- 4 Extinguisher configurations from 3 suppliers
 - N₂ charged with solenoid valve
(Abrams, BFV, FAASV, STRYKER, UAH, & some MRAP)
 - N₂ charged with linear actuated valve (NLOS-C Crew & Mission)
 - N₂ charged with SQUIB actuated valve (some MRAP)
 - Hybrid Fire Extinguisher actuated by Gas Generator (experimental)



Test Fires



Unsuppressed



Suppressed



Selected Crew Casualty Criteria



Parameter	Requirement ^a	Test ^b
Fire Suppression	Extinguish all flames without reflash	Y
Skin Burns	Less than second degree burns ($<2400^{\circ}\text{F}\cdot\text{sec}$ over 10 seconds or heat flux $< 3.9 \text{ cal/cm}^2$)	c
Overpressure ^{d,e}	Lung damage $<11.6 \text{ psi}$; Ear damage $\leq 4 \text{ psi}$	Y
Agent Concentration	Not to exceed Lowest Observed Adverse Effects Level	Y
Acid Gases ($\text{HF} + \text{HBr} + 2 \cdot \text{COF}_2$)	Less than 746 ppm-min (5 min dose)	Y
Oxygen Levels ^d	Not below 16%	Y
Discharge Impulse Noise ^f	No hearing protection limit: $<140 \text{ dBp}$ Single hearing protection limit: $<165 \text{ dBp}$	N
Discharge Forces ^{a,g}	Not to exceed 8 g and $<20 \text{ psi}$ at 5 inches	N

(a) Based on "Medical Evaluation of Non Fragment Injury Effects in Armored Vehicle Live Fire Tests," Walter Reed Army Institute of Research, September 1989 except as noted.

(b) Addressed in Exploratory Tests.

(c) Temperature recorded with thermocouples.

(d) "Fire Survivability Parameters for Combat Vehicle Crewmen," Memo to the US Army Surgeon General, 20 February 1987.

(e) "Noise Specification for Automatic Fire Extinguishing Systems (AFES)," Dept. of the Army Memorandum, 14 Nov 2013

(f) "Hearing Conservation Program," US Army Pamphlet 40-501, 10 December 1998.

(g) "Evaluation of Potential Physical Injury from Mechanical Forces Due to Automatic Fire Extinguisher System Discharge in the STRYKER Combat Vehicle: An Initial Assessment and Recommendations to Prevent Injury," Walter Reed Army Institute of Research, 21 August 2003

Overview of Results

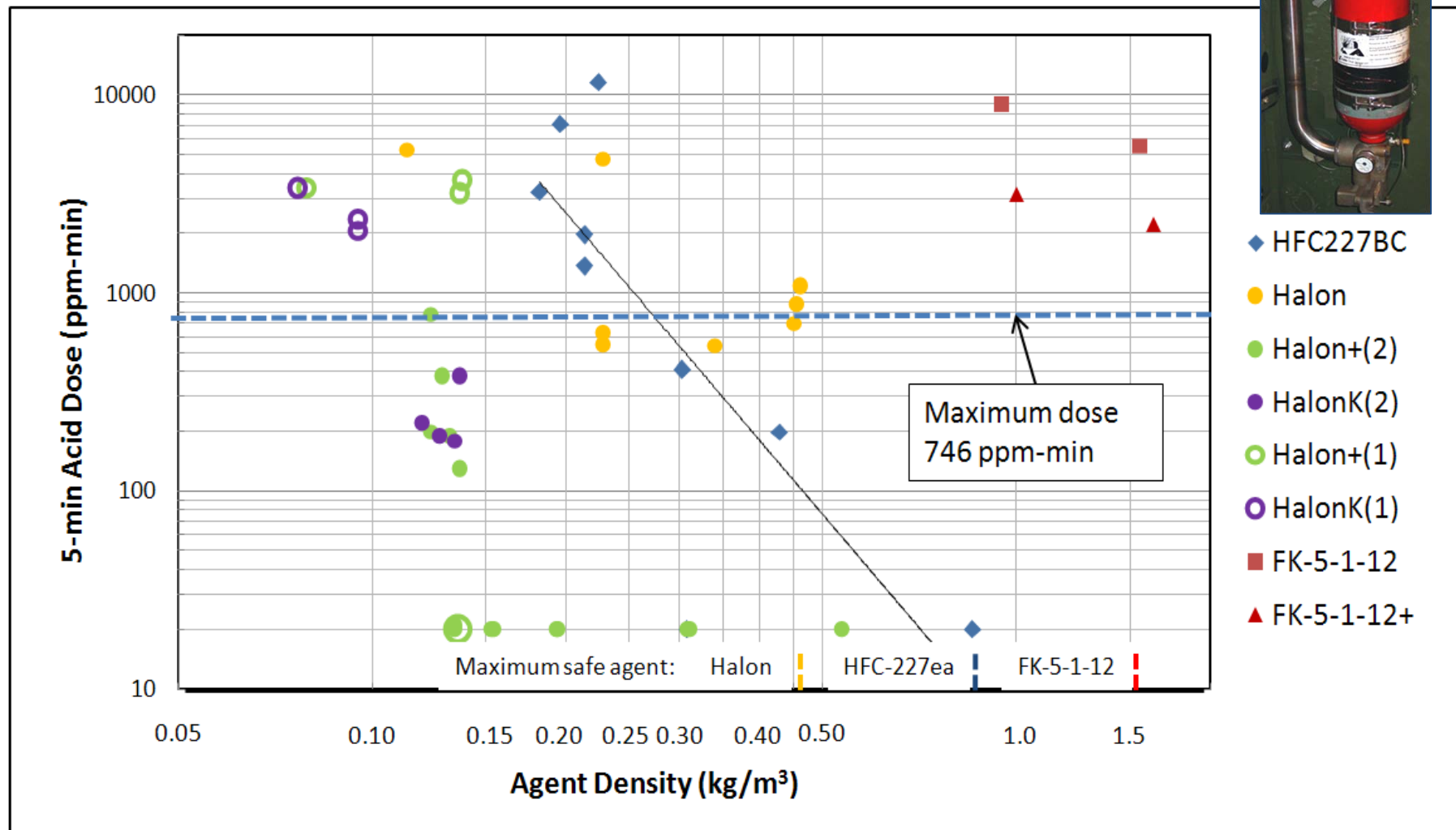


				**Best Performance			Note
Agent	Total	*Pass	**Least Agent Weight (lb)	Lowest Acid Dose (ppm-min)	Lowest Pressure Peak (psi)	Fastest Fire Out Time (ms)	
Halon	21	12	~5	~500	<1	<200	Legacy fielded product
Halon+	19	16	~2.5	<20	<1	<200	New mix compatible with fielded extinguishers
HalonK	7	4	~2.5	<20	<1	<200	New mix compatible with fielded extinguishers
HFC227BC	36	17	~5	<20	<1	<200	Fielded product
FK-5-1-12	21	0	>25	~2,000	1.2	<200	Available
FK-5-1-12+	15	0	>15	~1,300	1.6	<200	Invention required
Water+	23	12	~4	0	1.5	~400	Development required; operational issues?
NaBC	13	7	~3	0	<1	<200	Available; operational issues?
KBC	2	2	~2	0	<1	<200	Available; safety & operational issues?
Total	157	70					

* The goal was to 'pass' half the tests

** Best Performance and Least Agent Weight are not obtained simultaneously

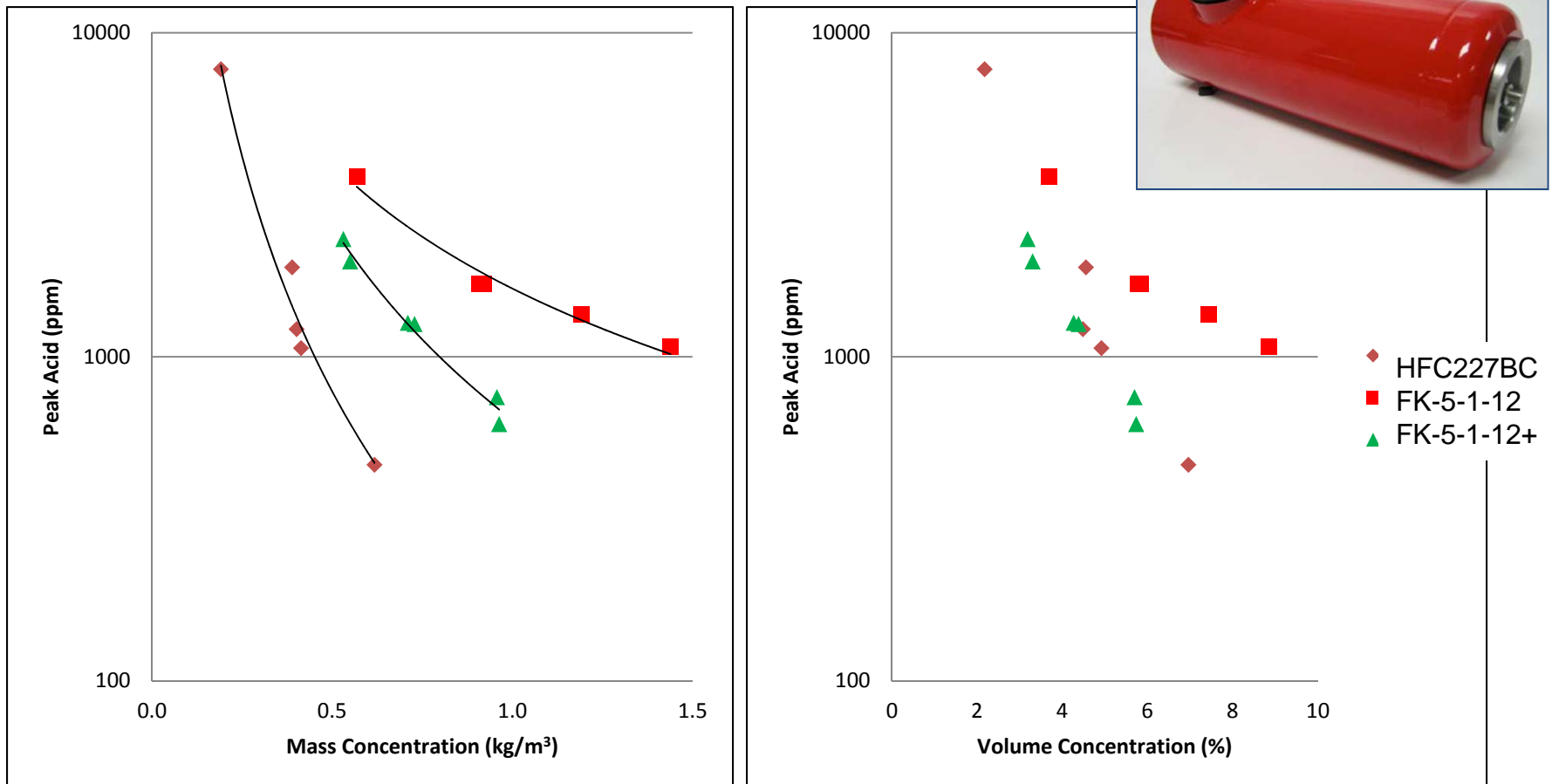
Comparison of Fluorinated Agents



Some Insight



- Acid vs. Mass and Volume Concentrations



Note: Although the peak acid levels for 'HFC227BC' and 'FK-5-1-12+' are similar, the integrated levels used in casualty assessments were very different: none of the FK-5-1-12-based tests 'passed.'

Results from 157 Tests using 9 agents indicate:

- Halon 1301 and HFC-227BC performed similarly, although Halon 1301 yielded relatively higher acid doses, consistent with earlier findings.
- FK-5-1-12 was not effective whether used alone or mixed with dry chemical due to high acid gas levels.
- Dry chemical and water with additives may become viable but further analysis, development and testing are required.
- When used as the sole suppression agent, potassium-bicarbonate-based dry chemical is almost twice as effective by weight as sodium-bicarbonate-based dry chemical, consistent with earlier findings.
- Mixes of Halon with sodium- or potassium-bicarbonate-based dry chemicals performed similarly.
- Halon with sodium- or potassium-bicarbonate-based dry chemicals is twice or more as effective by weight as currently deployed crew agents (Halon and HFC-227BC). This result has been verified in vehicle tests.
- None of the non-Halon agents as evaluated are drop-in replacements for Halon or HFC-227BC.

Low/No GWP Agents – Project Proposal



- What is the intended end product?
 - The end product of this project is an evaluation of the technical feasibility of emerging low GWP fire extinguishing agents for US Army ground vehicle and aviation weapon system applications.
 - The scope includes ground vehicle crew and engine compartments, aviation engine and auxiliary power unit (APU) compartments, and portable extinguishers.
- What is the technical approach?
 - The technical approach of this joint TARDEC/AMRDEC evaluation effort will look for replacements for the high GWP agents currently used: Halon 1301 and HFC-227ea. Our search for new low or no GWP agents will include:
 - Market survey and determination of chemical properties
 - Toxicity evaluation of candidate agents
 - Long-term storage and material compatibility of agent mixtures and storage containers
 - Agent distribution/hardware/technology development with modeling and simulation
 - Fire-fighting performance testing and optimization
- What specific applications will product transition to?
 - If economically/technically feasible technologies are identified they could, with PM support, be transitioned to:
 - All current and anticipated combat and up-armored tactical ground vehicles
 - Candidates for new aviation systems
 - Legacy systems retrofits

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